Status of the UV Cure Powder Coating Demonstration Project

Report Documentation Page

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Outline

- Project Team
- UV Cure Technology
- UV Curable Powder Overview
- UV Cure Powder Coating Demonstration/Validation

Project Team

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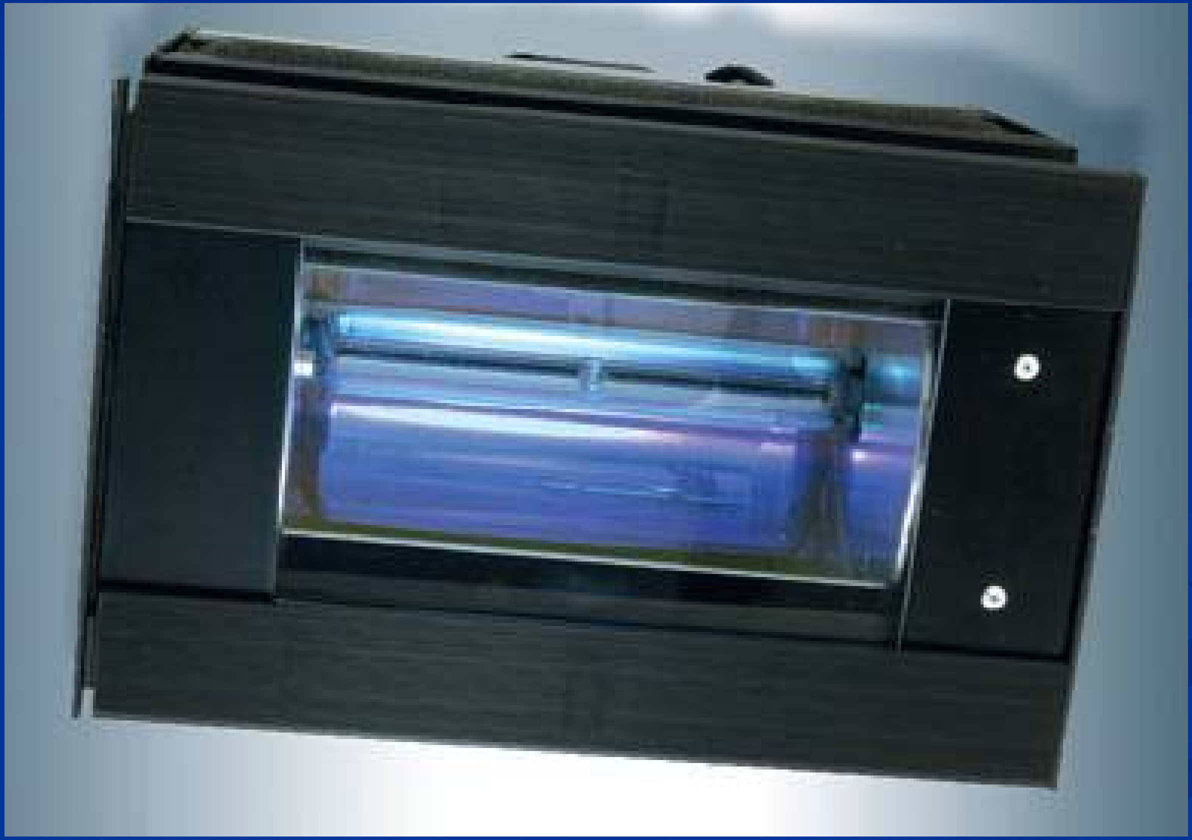
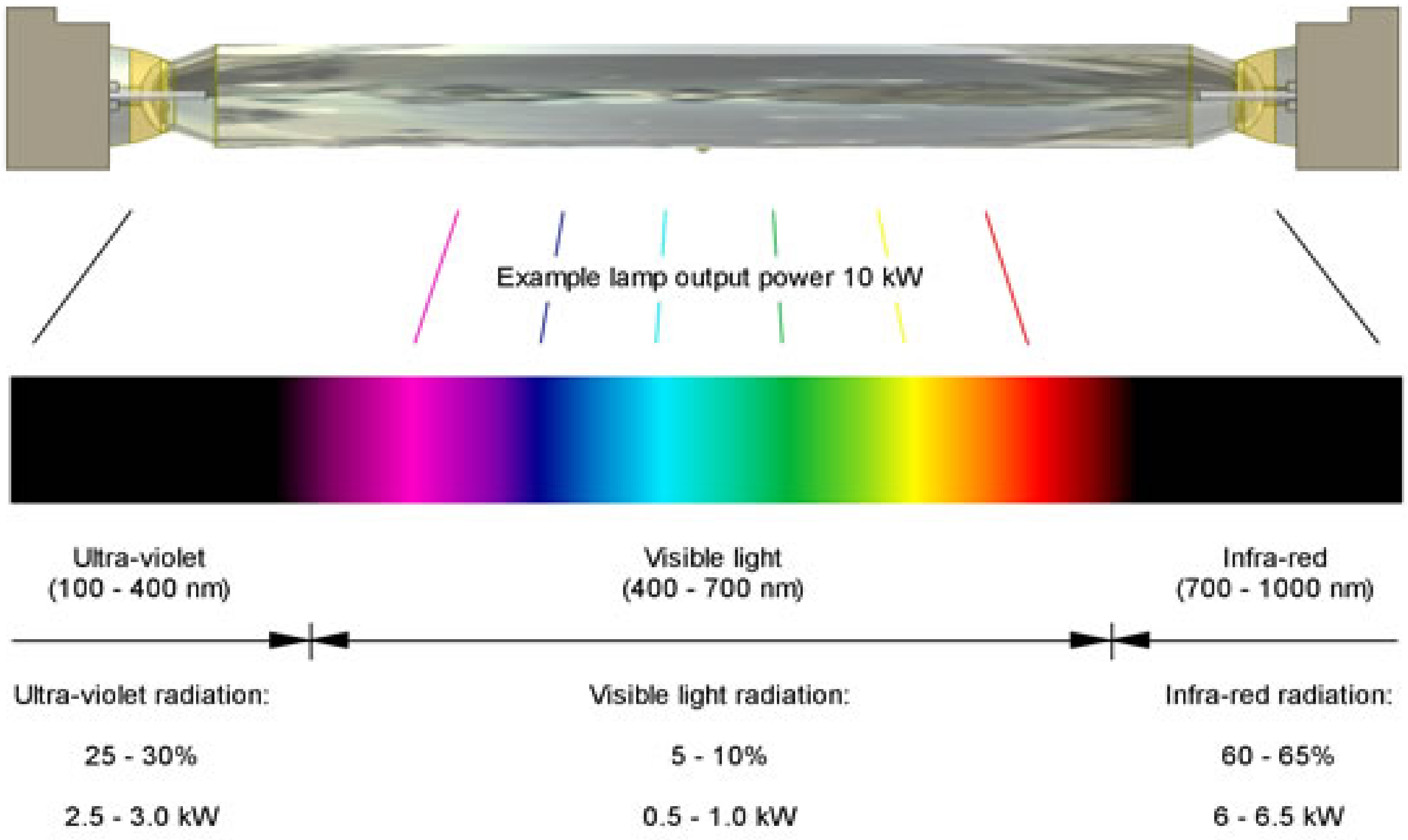
UV Cure Technology

UV Cure Technology

- Requires a source of UV light



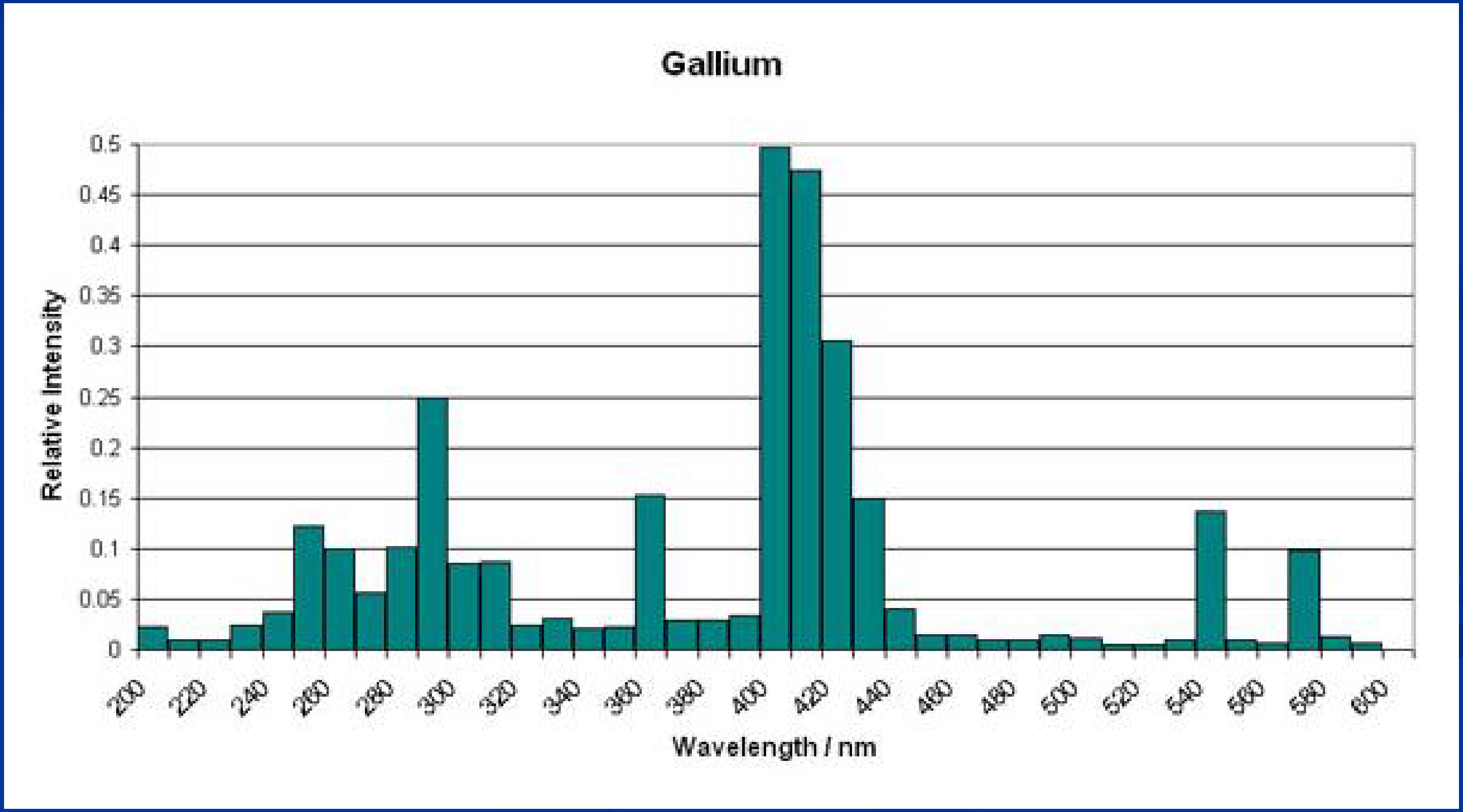
UV Cure Technology



Typical medium pressure mercury discharge lamp power distribution.

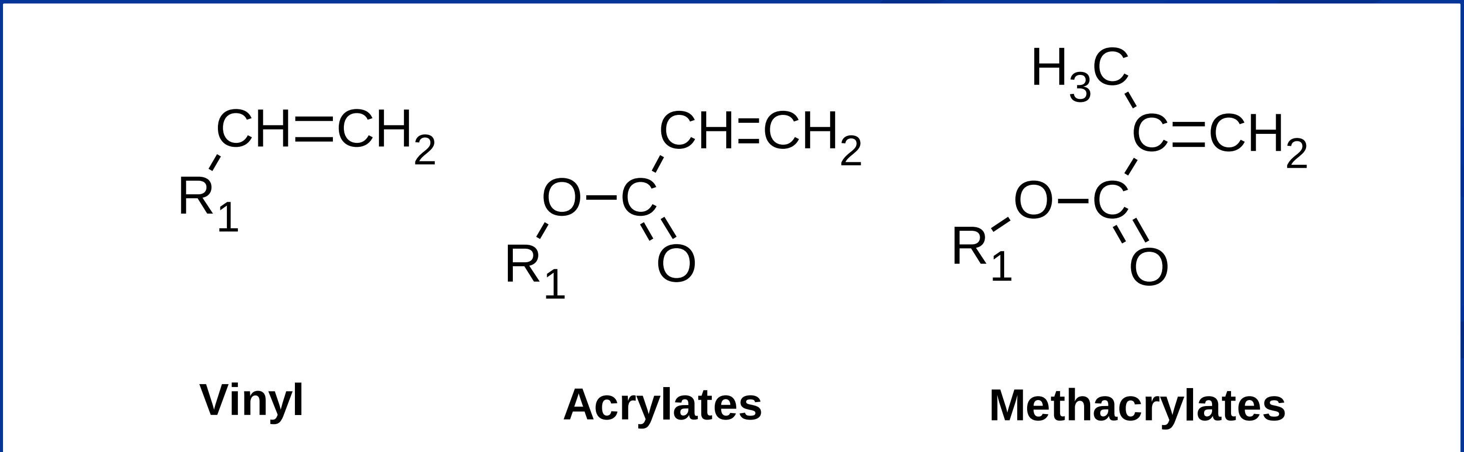
UV-Cure Technology

- We use a Gallium doped lamp:



UV Cure Technology

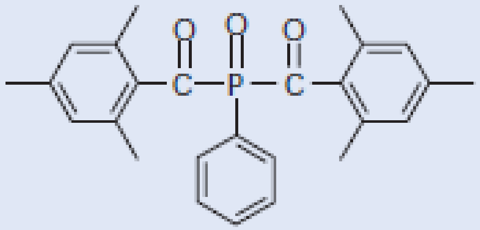
- Chemistry of UV-cure coatings
  - Can be virtually any polymer matrix used for organic coatings
  - The common denominator is the presence of a UV light reactive species on/in the polymer matrix
  - Commonly vinyl, acrylate or methacrylate groups



UV Cure Technology

- UV Cure formulations require:
  - Light reactive polymer resins
  - Additives such as pigments and flow agents
  - Photoinitiators

IRGACURE 819 and IRGACURE 819 DW



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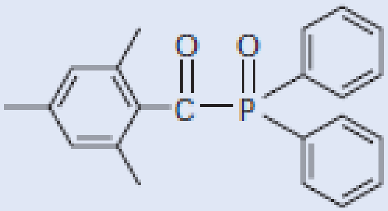


UV Cure Technology

- UV-cure powder coatings
  - Typically, the most common UV curable powders are:
    - Polyurethanes
    - Polyesters
    - Epoxies
    - Hybrids and mixtures of the above
  - For the UVCPC project, we use a special composition of light activated polyurethanes and polyesters

UV Curable Powder Overview

UV-Curable Powder Overview

- Previous ways of thinking about powder
  - Coating cure temperatures – typically above 220°C
  - Prohibitive for use on tempered metals (Al, Mg, Ti)
  - Prohibitive to use on composites
  - Powder coatings were designed as barrier protection

UV-Curable Powder Overview

- Modern powder coatings can be formulated to have:
  - Lower melt & flow temperatures (< 110°C)
  - UV or EB cure functionality can be added
  - Various advanced non-chrome corrosion inhibitors

UV-Curable Powder Overview

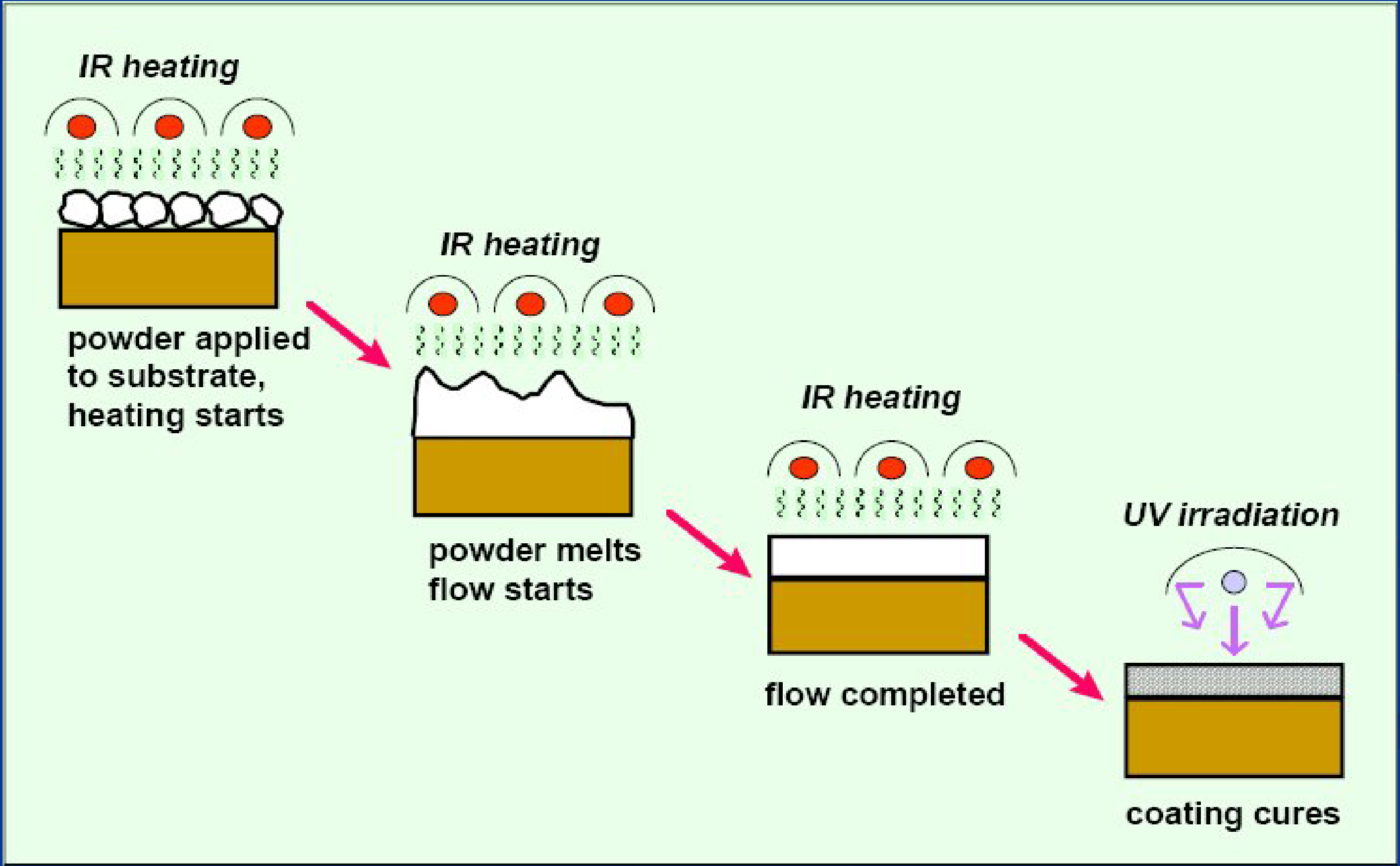
- Advantages of UV-cure powder coating:
  - Elimination of volatile organics (VOC)
  - Elimination of hazardous air pollutants (HAP)
  - Reduction/elimination of hazardous waste
  - Transfer efficiencies as high as 95% (w/reclaim)
  - Decrease in thermal exposure.
  - Large bulky parts that cannot fit into existing ovens can be coated and cured.
  - UV-cure powder requires less energy because the energy is focused to a specific part only as long as needed.

UV Curable Powder Overview

- Powder is applied using electrostatic powder gun
- Applied powder is cured with IR and UV lights mounted on robotic curing system

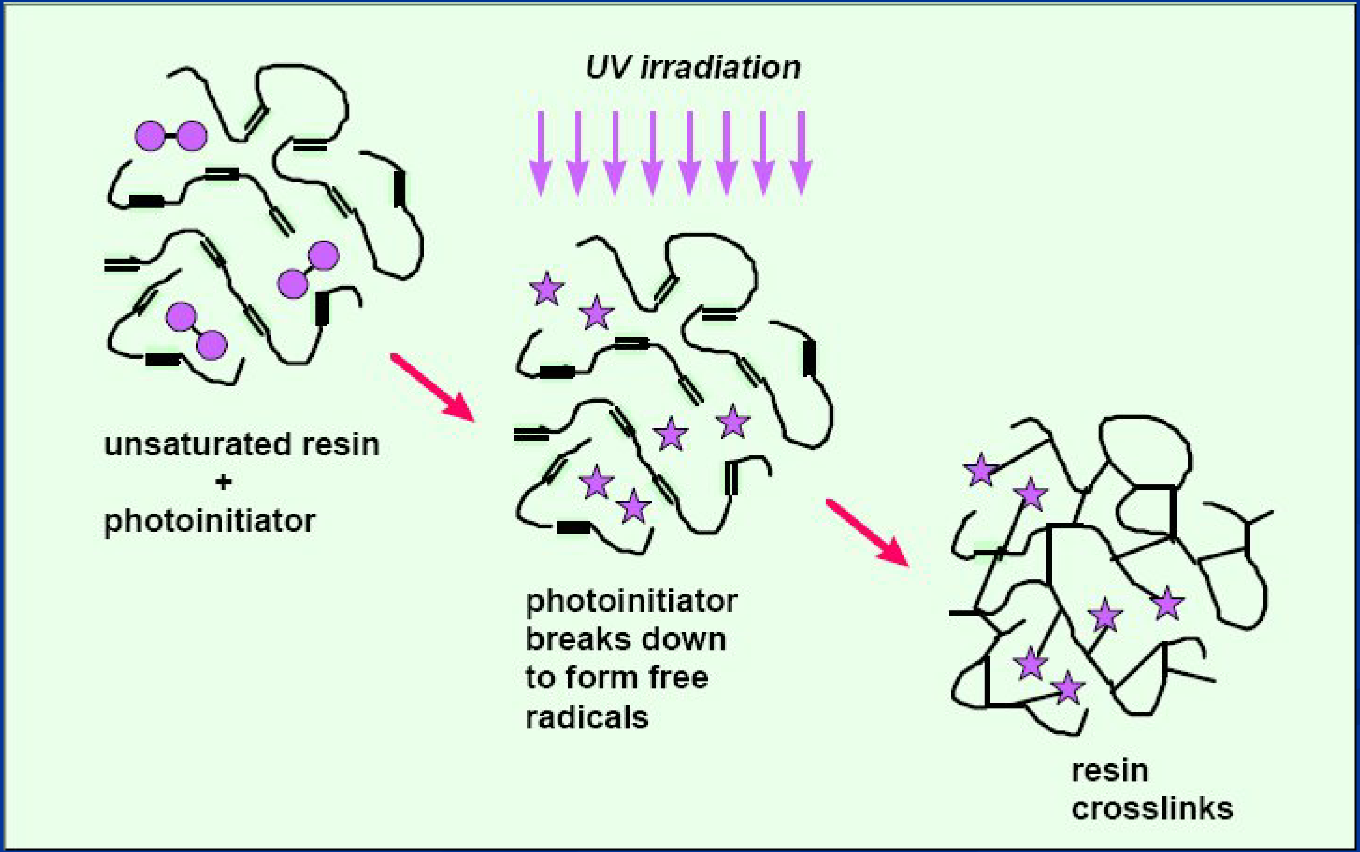
UV Curable Powder Overview

- The UV cure powder process:



UV Curable Powder Overview

- Crosslinking occurs during UV irradiation:



UV Cure Powder Coating Demonstration/Validation

UVCPC Dem/Val

- Timeline
  - Project based on Commercial Off The Shelf (COTS) UV cured powder coatings
  - Project started in 2008
  - Initially had two powder vendors
  - One dropped because of constant merger issues
  - Initial validation testing completed in 2010
    - Results questionable due to adhesion issues
    - A number of tests rerun as a result
  - Adhesion study completed in 2010
    - Found one of the reasons for poor adhesion

UVCPC Dem/Val

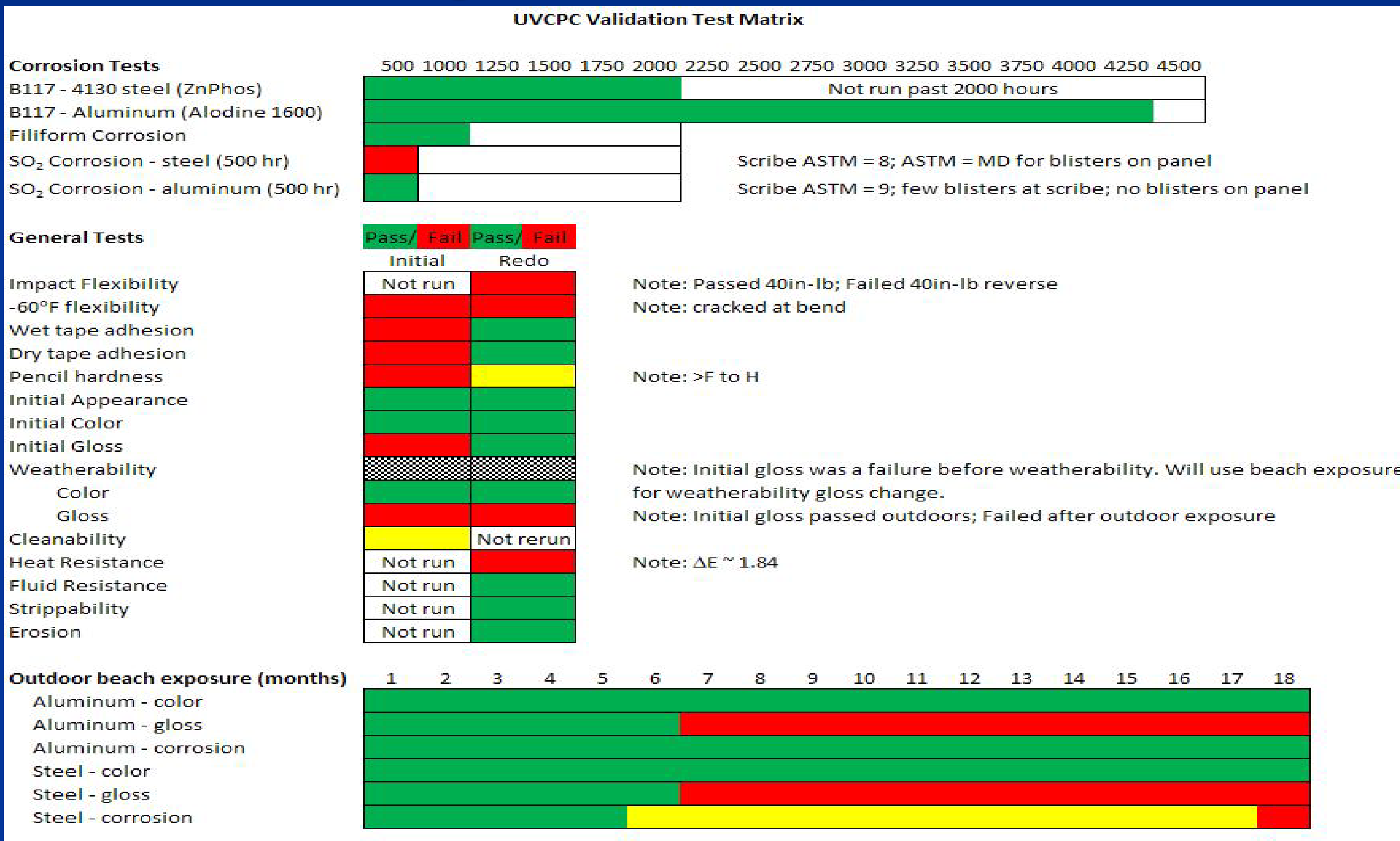
- Timeline (Cont.)
  - Adhesion study completed in 2010 (Cont.)
    - Low copper alloys (6000, 3000 series) not a problem
    - High copper alloys scavenge free radicals at surface
    - Determined that certain surface treatments are effective:
      - Anodized
      - Alodine 1600
      - Zinc Phosphate
      - Epoxy wash primers
  - Building 2801 modification completed end 2010
  - Robot installation occurred in 2011

UVCPC Dem/Val

- Timeline (Cont.)
  - First light and testing in early 2012
    - Discovery that kinetics also play major role in adhesion
  - First parts coated with UVCPC
    - Ammo can
    - Aircraft jack hydraulic reservoirs
    - USAF aircraft wheels

UVCPC Dem/Val

- Validation Testing Results (Summary) of COTS UVCPC



UVCPC Dem/Val

- General test results
  - Color (FED-STD-595C)

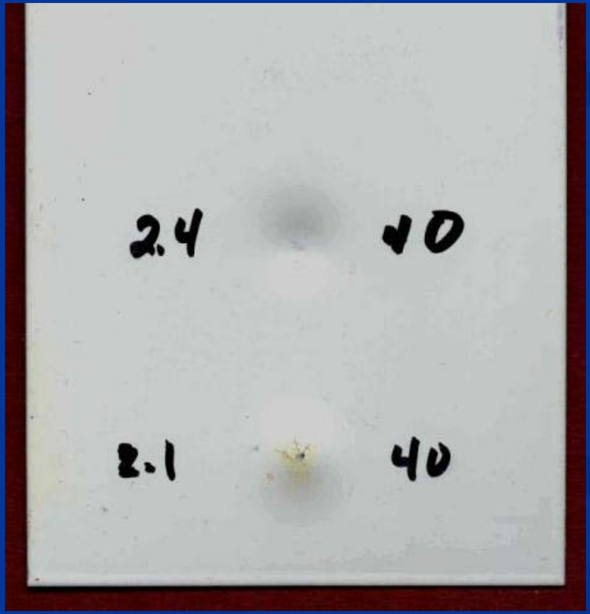
Coating	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
FED-STD-595C 17925 Reference Chip	96.06	-1.95	3.10				
PCRG High Gloss White	95.82	-1.96	2.66	-0.24	-0.01	-0.45	0.5
FED-STD-595C 26173 Reference Chip	55.05	-1.24	-3.66				
PCRG Semigloss Initial	55.13	-1.24	-3.98	0.08	0.00	0.32	0.2

  - Gloss (FED-STD-595C)

Sample ID		20°	60°	85°
PCRG High Gloss White		55.1	84.4	95.6
PCRG Semi Gloss Initial		8.8	45.8	78.1

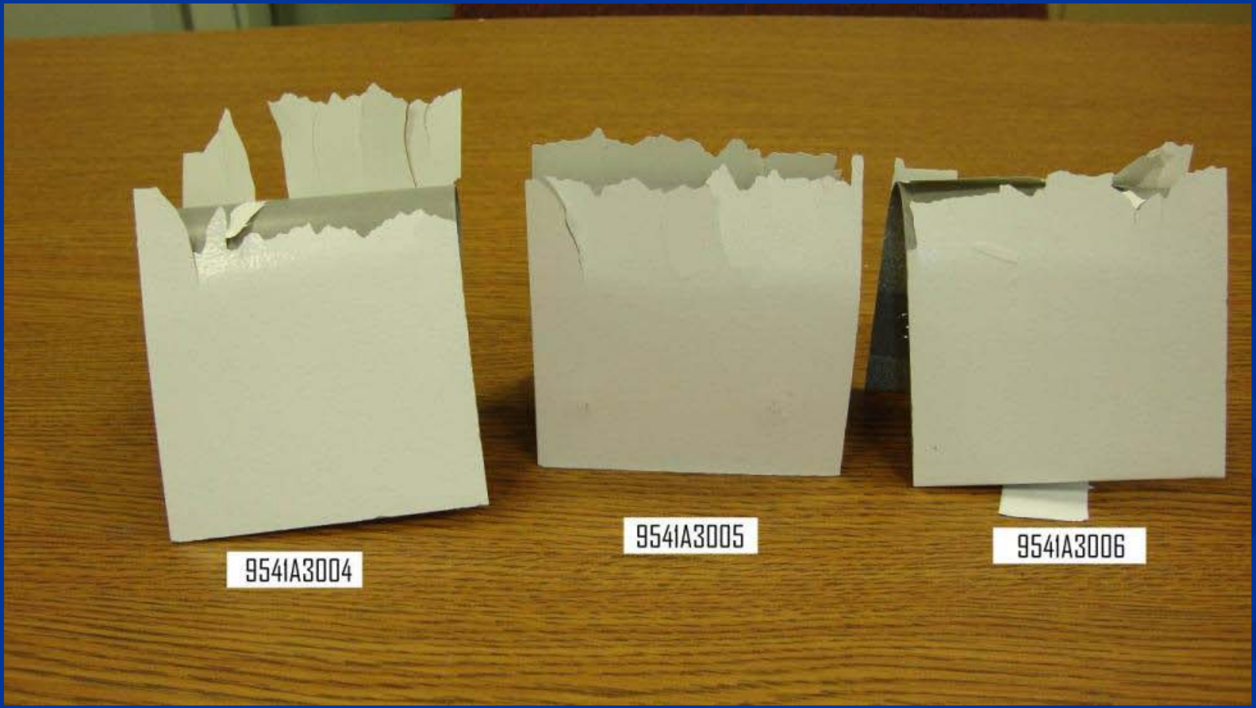
UVCPC Dem/Val

- General test results
  - Pencil Hardness (ASTM D3363)
    - Marginal, falls between F and H pencil
  - Impact Flexibility (MIL-PRF-85285D)
    - Passed 40 in-lb forward, Failed 40 in-lb reverse



UVCPC Dem/Val

- General test results
  - Low temperature (-60°F) flexibility initial (MIL-PRF-85285D)



UVCPC Dem/Val

- General test results
  - Low temperature (-60°F) flexibility rerun

UVCPC Dem/Val

- General test results
  - Dry/Wet tape adhesion (ASTM D3359, FED-STD-141D)
    - Initial results were failures due to adhesion issue
  - Dry adhesion was rerun on various pretreatments
    - Because adhesion seemed to change with time, a month of testing run
    - Summary of the dry tape adhesion results is shown on next slide

UVCPC Dem/Val

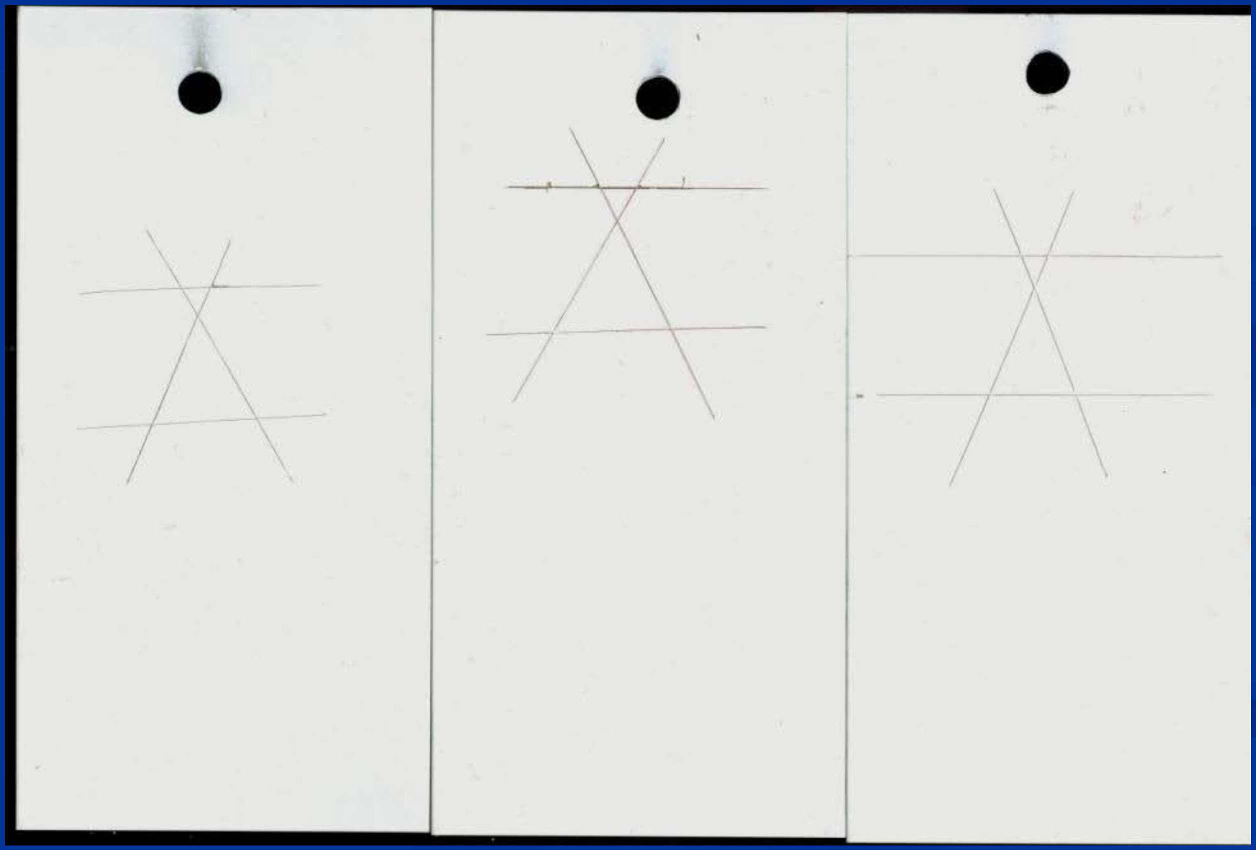
- General test results

	Film Thickness	Cross Hatch Adhesion							
		1/5/2011	1/7/2011	1/10/2011	1/12/2011	1/14/2011	1/17/2011	1/19/2011	2/3/2011
Alodine 1200S									
45 sec	1.3 - 1.4	4B	4B	4B	4B	4B	2B	2B	N/A
90 sec	1.5 - 1.8	4B	3B	3B	3B	3B	3B	2B	N/A
3 min	1.7 - 2.2	4B	2B	2B	0B	0B	0B	0B	N/A
Alodine 1600									
1 min	1.7 2.1	5B	5B	5B	5B	5B	5B	5B	4-5B
3 min	1.5 - 1.7	5B	5B	5B	5B	5B	4-5B	4-5B	4-5B
5 min	1.4 - 1.7	5B	5B	5B	5B	5B	4-5B	4-5B	4-5B
20 sec	1.6 - 2.0	5B	5B	4-5B	4-5B	4-5B	4-5B	4-5B	4-5B
Alodine 5200									
1 min	1.3 - 1.5	5B	5B	5B	5B	5B	5B	5B	N/A
2 min	1.5 - 1.8	5B	5B	5B	5B	5B	5B	5B	N/A
4 min	1.5 - 2.0	4B	4B	4B	5B	4-5B	5B	5B	N/A
Alodine 5900									
5 min	1.3 - 1.4	4B	4B	3B	3B	2B	0B	0B	N/A
10 min	1.2 - 1.5	4B	3B	3B	2B	2B	0B	0B	N/A
Alodine 8800									
Heavy	1.6 -1.7	5B	5B	5B	5B	5B	5B	5B	N/A
Light	1.5 - 1.7	5B	5B	5B	5B	5B	5B	5B	N/A
Control	1.5 - 1.9	0B	0B	0B	0B	0B	0B	0B	N/A
Carpenter B/700								5B	33 days

S-W Wash Primer	**Test**	**Initial + 2 week**
2024-T3	Dry	5B + no change
2024-T3	Wet	5B + no change
4130 steel	Dry	5B + no change
4130 steel	Wet	5B + no change

UVCPC Dem/Val

- General test results
  - Wet tape adhesion



UVCPC Dem/Val

- General test results
  - Fluid resistance (MIL-PRF-85285D)
  - Initial fluid resistance test halted as soon as adhesion issue discovered
  - Follow on fluid resistance test rerun passed

UVCPC Dem/Val

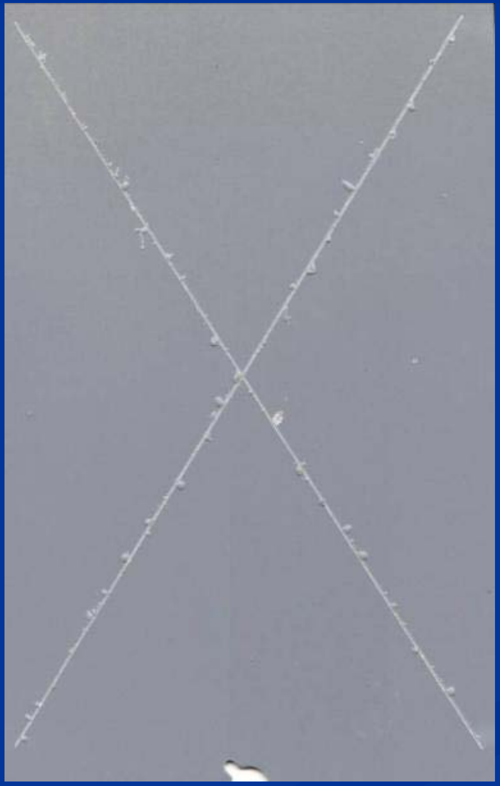
- General test results
  - Weatherometer (MIL-PRF-85285D, ASTM G155)
    - 500 hour test
    - $\Delta E^* = 0.97$ (Pass)
    - Gloss loss ≈ 63.7 units (Fail)
  - Heat Resistance (MIL-PRF-85285D)
    - $\Delta E^* = 1.84$ (Marginal)
  - Cleanability (MIL-PRF-85285D)
    - Efficiency = 67% (Marginal)
  - Strippability (MIL-PRF-85285D)
    - 100% removed in < 4 hours (Pass)

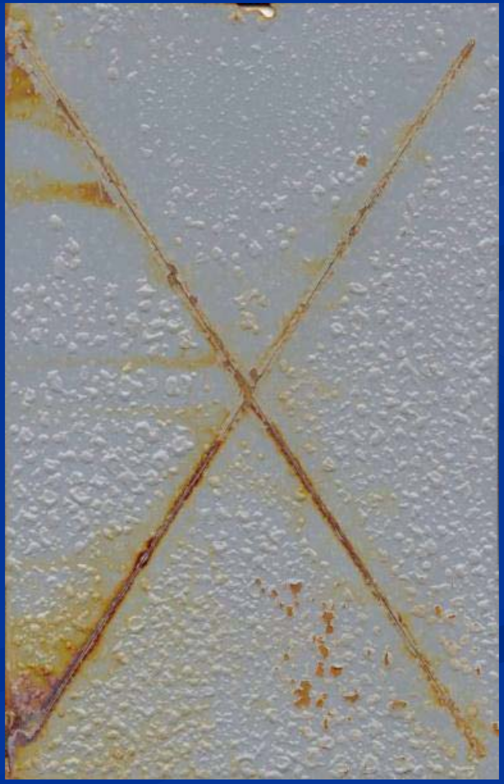
UVCPC Dem/Val

- Corrosion resistance tests
  - Neutral salt fog (MIL-PRF-23377J, ASTM B117)
    - UVCPC over Zn Phosphate 4130 steel, 2000 hrs (Pass)
    - UVCPC over Alodine 1600, 2024-T3 Al, 4430 hrs (Pass)

UVCPC Dem/Val

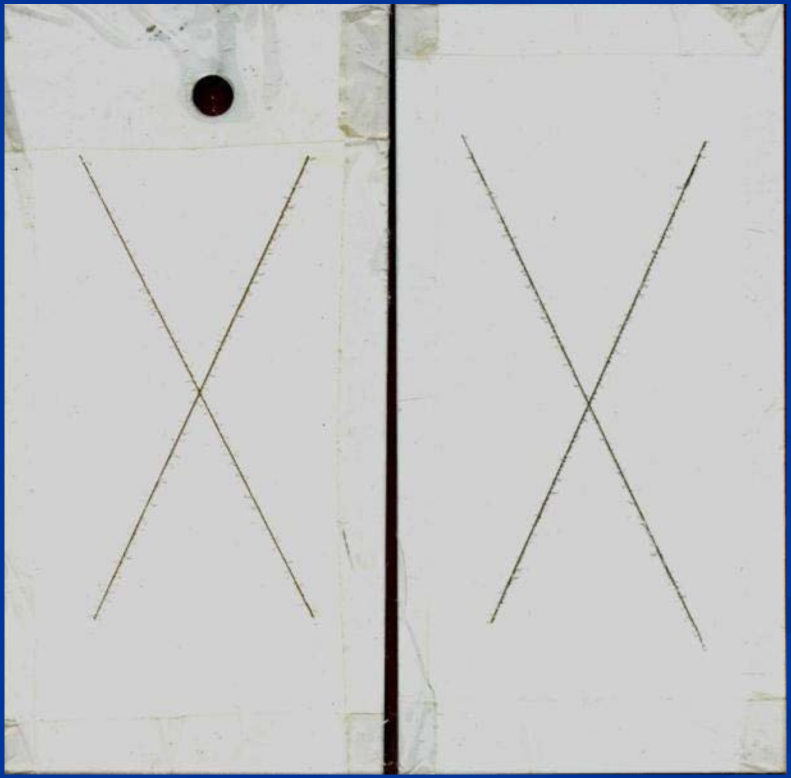
- Corrosion resistance tests
  - SO_2 corrosion resistance (ASTM G85, Annex 4)
    - UVCPC over Aluminum (Pass)
    - UVCPC over cold rolled steel (Fail)





UVCPC Dem/Val

- Corrosion resistance tests
  - Filiform corrosion resistance (MIL-PRF-23377J, ASTM D2803)
    - 1000 hour test (Pass)



UVCPC Dem/Val

- Erosion/Abrasion tests
  - Falling sand erosion testing (ASTM D968)
    - Within 1σ of the legacy coating

Falling Sand Evaluation (UVCPC)

Sample #		Liters (V)		Mean thickness (t)		A Factor A=V/t
2		144		2.32		62.1
3		162		2.8		57.9
4		144		2.53		56.9
5		133		2.53		52.6
6		144		2.58		55.8
8		143		2.49		57.4
					Mean	57.0
					Std Dev	3.09

UVCPC Dem/Val

- Long term outdoor exposure (ASTM D1014)
  - Three parameters evaluated
    - Color drift
    - Gloss drift
    - Overall corrosion
  - Semi-gloss gray UVCPC used
  - Results:
    - Color drift maximum $\Delta E^* = 0.82$ (Pass)
    - Gloss drift 36.6 gloss units (Fail)
    - Corrosion overall:
      - Aluminum still passing after 18 months (~12900 hours exposure)
      - Cold rolled steel failed after 7 months (~5000 hours exposure)

UVCPC Dem/Val

- Long term outdoor exposure
  - Color drift

Coating	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
FED-STD-595C 26173 Reference Chip	55.05	-1.24	-3.66				
PCRG Semigloss Initial	55.13	-1.24	-3.98	0.08	0.00	0.32	0.2
PCRG 7-month color	55.40	-1.18	-4.16	0.35	-0.06	0.50	0.32
PCRG 12-month color	55.77	-1.16	-4.11	0.72	-0.08	0.45	0.75
PCRG 18-month color	55.82	-1.21	-4.17	0.76	-0.07	0.31	0.82

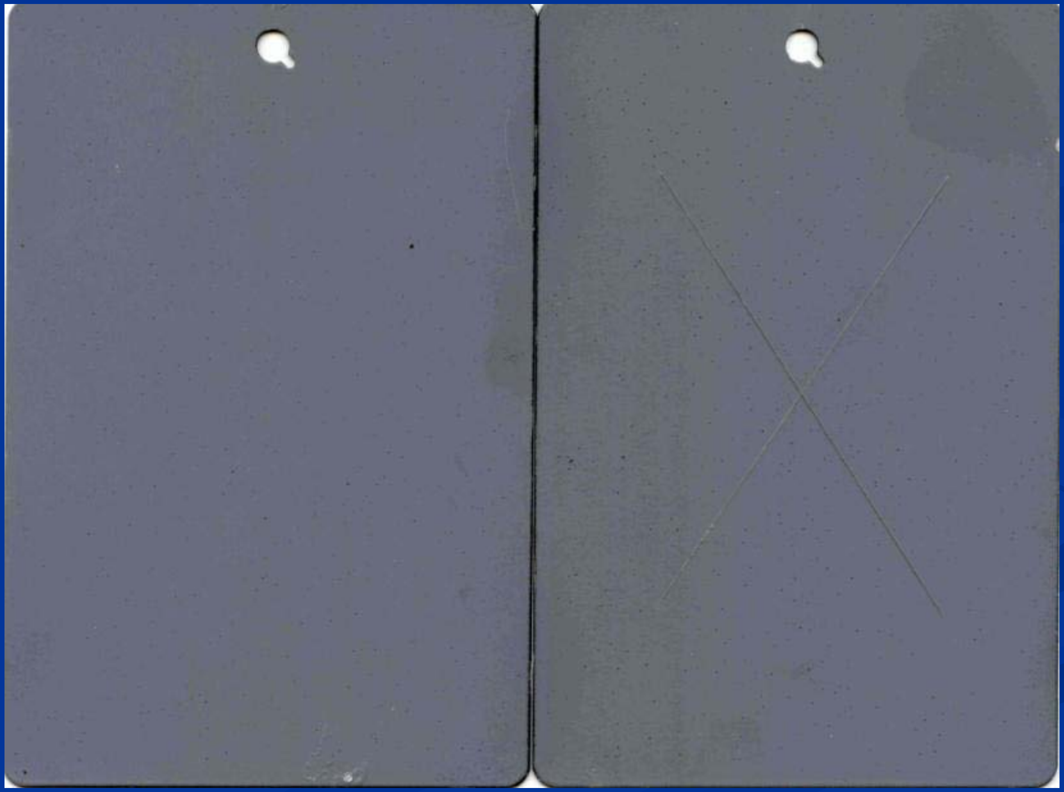
UVCPC Dem/Val

- Long term outdoor exposure
  - Gloss drift

Sample ID		20°	60°	85°
PCRG Semi Gloss Initial		8.8	45.8	78.1
PCRG 7-month semigloss		3.0	25.7	66.9
PCRG 12-month semigloss		2.2	21.9	60.2
PCRG 18-month semigloss		0.9	9.2	41.6

UVCPC Dem/Val

- Long term outdoor exposure
  - Aluminum after 18 months (~12,900 hours)



UVCPC Dem/Val

- Long term outdoor exposure
  - Steel after 7 & 18 months

UVCPC Dem/Val

- Actual components coated
  - Ammunition can

UVCPC Dem/Val

- Actual components coated
  - Aircraft jack hydraulic reservoirs

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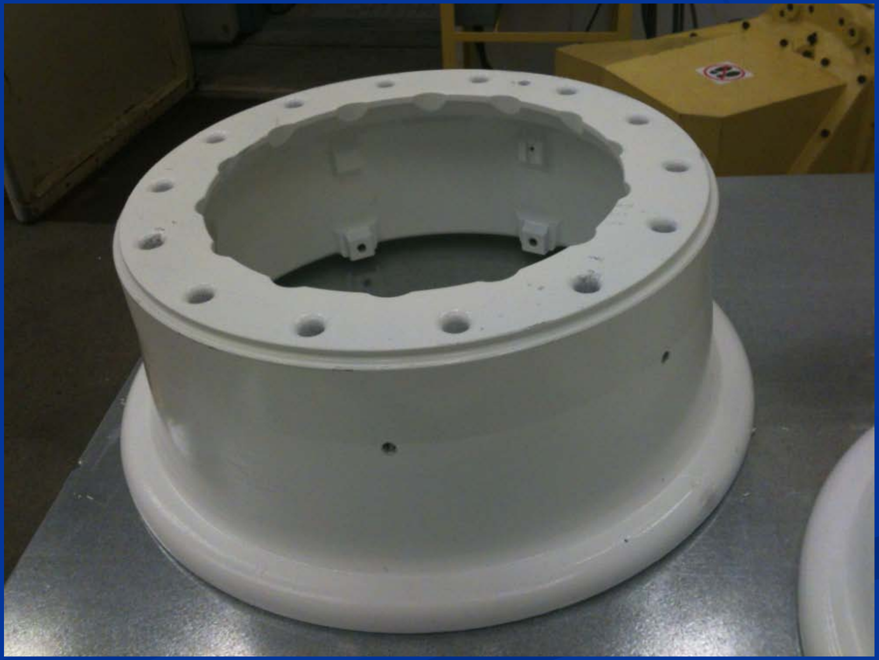
UVCPC Dem/Val

- Actual components coated
  - F-16 main wheel (before)




UVCPC Dem/Val

- Actual components coated
  - F-16 main wheel (after)

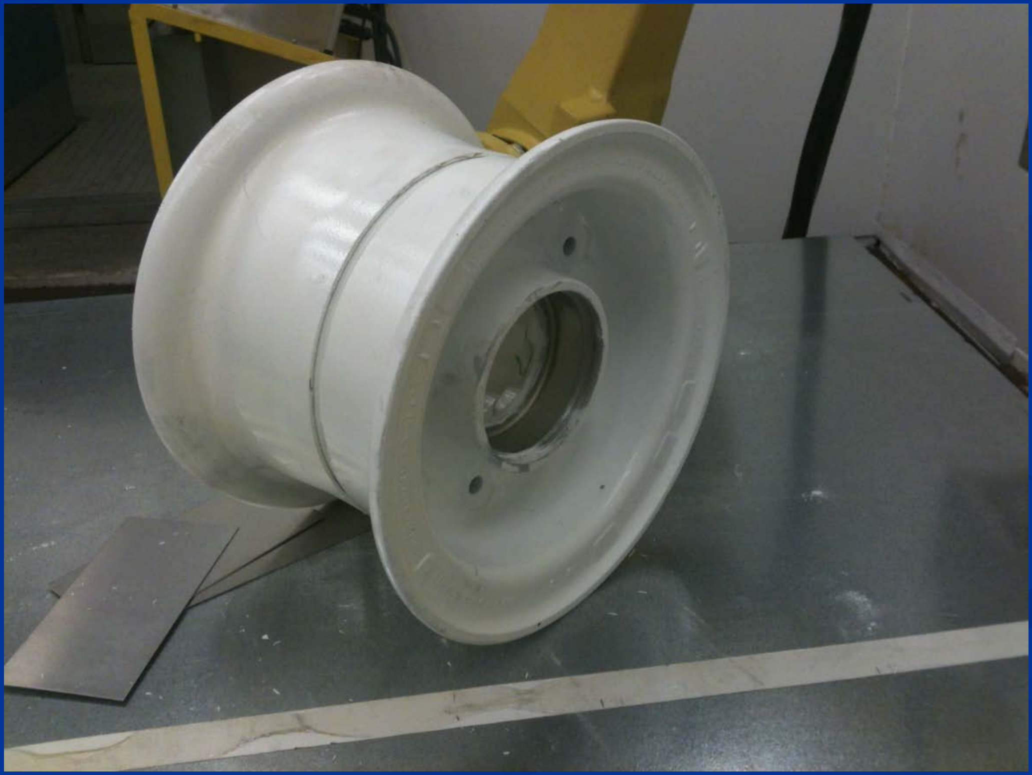


UVCPC Dem/Val

- Actual components coated
  - F-15 nose wheel (before)

UVCPC Dem/Val

- Actual components coated
  - F-15 nose wheel (after)



UVCPC Dem/Val

- Actual components coated
  - Coast Guard MC-130 landing gear door

Summary

- Overall, the COTS UVCPC did well
  - Better overall test results than previous Low Temp powder
  - Positives
    - Excellent B117 corrosion resistance over aluminum
    - Good corrosion resistance over zinc phosphated steel
    - Excellent Filiform corrosion resistance
    - Good room temperature flexibility
    - Erosion resistance on par with legacy 2K coatings

Summary

- Overall, the COTS UVCPC did well (cont.)
  - Could use some improvements going forward
    - Coating
      - Lower melt/flow temperature
      - Improve -60°F flexibility
      - Increase hardness to 2H or greater pencil
      - Improve impact flexibility
      - Better heat resistance
      - Improve weatherability (gloss)
      - Reformulate for direct-to-metal

Summary

- Overall, the COTS UVCPC did well (cont.)
  - Could use some improvements going forward
    - Robotics
      - Better profiling
        - Use profiling radiometers
        - Better thermal profiling
      - Better control during operations (thermal, UV)
        - IR and UV feedback to robot
    - Powder Coating
      - Incorporate non-contact uncured powder thickness gauge

Questions?

UVCPC Back up slides

UVCPC Adhesion

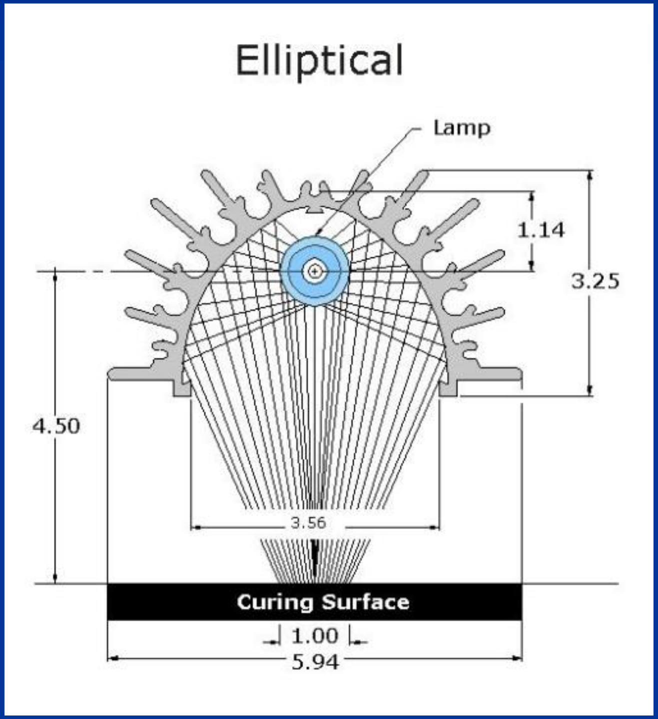
- Adhesion of UVCPC over 2000 series aluminum
  - Adhesion results could not be duplicated between CTIO and PCRG
    - Key differences between locations was power of UV lamps
    - Formulation developed under a 300 Watt/in lamp
    - Originally thought it was photoinitiator based
    - "Flash" effect considered
  - Determined to test on the robotic curing system at NASWI
    - Nordson lamp is power adjustable unlike the CTIO/PCRG lamps
    - Robot can duplicate conveyor speeds (5 fpm vs. 9 fpm)
    - Robot can execute multiple passes in programming
    - Felt that the system could duplicate either lab
    - However, the results were completely unexpected
    - Realized the lamp at NASWI is a non-focused lamp
  - NASWI results led to the belief that both chemistry and kinetics play a role in the cure and adhesion on metallic substrates

UVCPC Adhesion

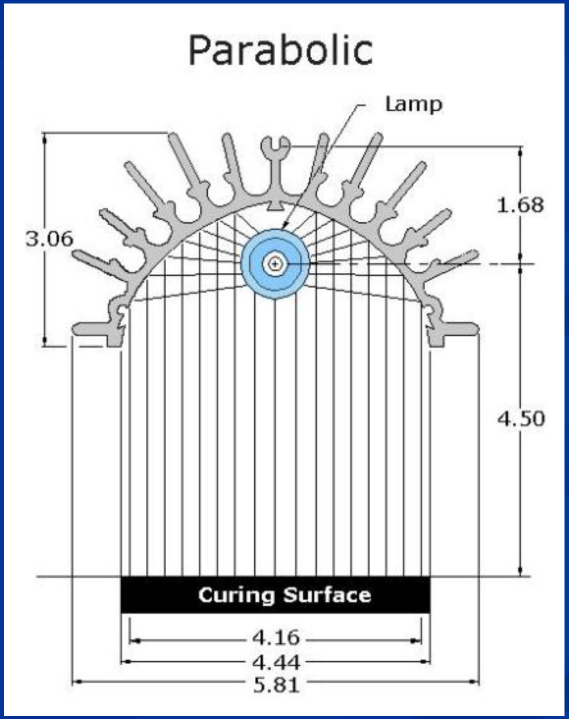
- Adhesion of UVCPC over 2000 series aluminum
  - The robotic curing system was able to cure with 5B adhesion
    - 5086, 6061, 3003 aluminum, and 4130 steel
    - None of the test panels had been prepared
      - Wiped free of dust
      - No pretreatment
      - No scuffing of surface (except steel which was bead blasted)
    - On 2000 series untreated, unprepared aluminum, 3B to 4B adhesion was possible
  - Kinetics plays a role as well as free radical scavengers
    - Free radical concentration at an instant in time
    - Focused lamps vs. unfocused lamps

UVCPC Adhesion

- Adhesion of UVCPC over 2000 series aluminum
  - Focused vs. unfocused reflectors



Used by CTIO and PCRG



Used by NASWI

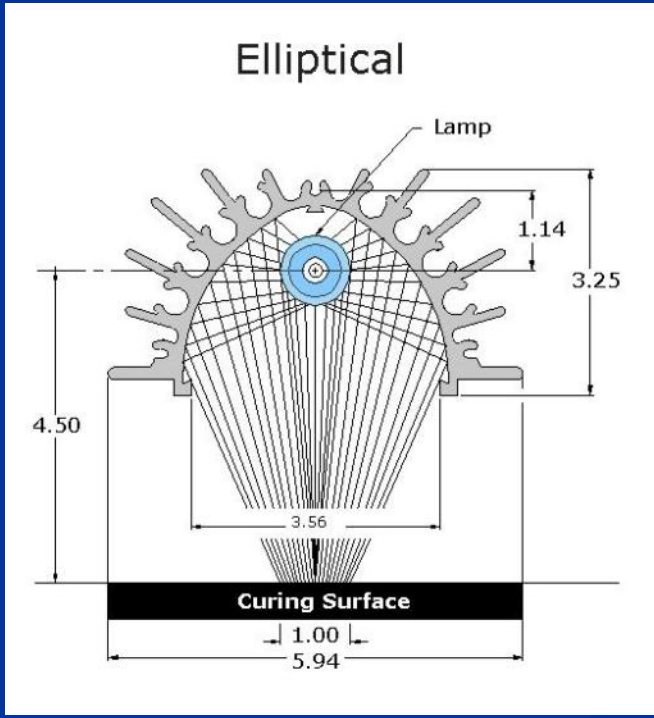
UVCPC Adhesion

- Adhesion of UVCPC over 2000 series aluminum
  - Focused vs. unfocused reflectors
  - Dose at each location (typical)

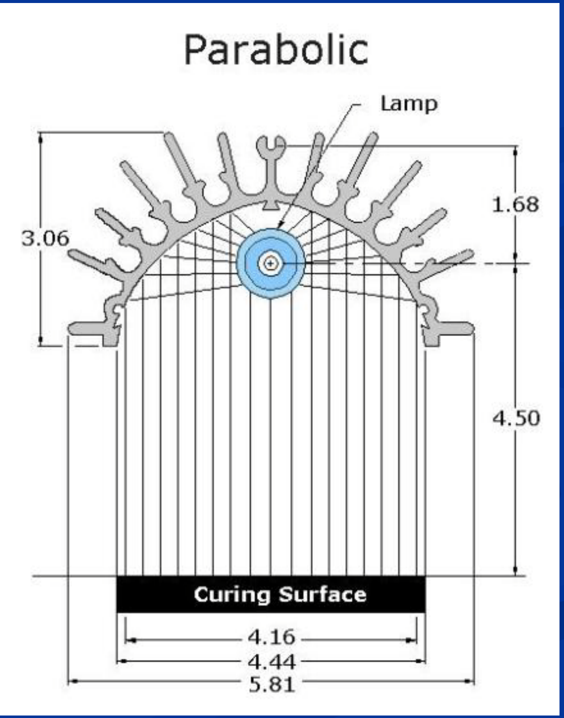
	WPAFB lamp (focused) J/cm^2 2-pass, 9 fpm	PCRG lamp (focused) J/cm^2 2-pass, 5 fpm	NASWI lamp (unfocused) J/cm^2 1-pass, ~4 fpm
UVA	2.54	2.22	1.53
UVB	1.83	1.39	1.62
UVC	0.13	0.17	0.22
UVV	12.7	10.41	12.23

UVCPC Adhesion

- Adhesion of UVCPC over 2000 series aluminum
  - Focused puts almost full dose in a 1" path
  - Unfocused puts similar dose down across ~4" path
    - Between 0.6 (WPAFB) and 1 (PCRG) second for full dose in focused
    - About 5 seconds (NASWI) for full dose in unfocused



Used by CTIO and PCRG



Used by NASWI

UVCPC Adhesion

- Adhesion of UVCPC over 2000 series aluminum
  - Kinetics of the cross linking reaction in UVCPC
  - Time based equations

$$v_i = 2k_d f[I]$$ Eq. (1) initiation

$$v_p = k_p[M][M\cdot]$$ Eq. (2) propagation

$$v_t = 2k_t[M\cdot]^2$$ Eq. (3) termination

UVCPC Adhesion

- Adhesion of UVCPC over 2000 series aluminum
  - Concentration of free radicals directly related to dose received
  - For a given "instant" in time:
    - WPAFB instantaneous free radical conc. is 3.4 times PCRG lamp
    - WPAFB instantaneous free radical conc. is 5.4 times NASWI lamp
    - Results in a relative increase of 11.6, or 29 time increase in v_t between WPAFB, PCRG, and NASWI lamps

$$v_p = k_p[M][M\cdot]$$

$$v_t = 2k_t[M\cdot]^2$$

  - If v_t is $\geq v_p$, then:
    - Premature termination
    - Excessive shrinkage
    - Low cross link density
    - No or poor adhesion

UVCPC Adhesion

- Summary of Adhesion Issue:
  - Copper or other free radical scavengers have an effect
    - Scavenger “effect” can be overcome with:
      - Certain chromate conversion coatings
      - Anodizing
      - Epoxy based wash primer
      - Adjustment “tweak” in formulation
  - Kinetics based on free radical concentration at an instant in time
    - Overcome termination rate by spreading the dose
    - A little longer cure is a “better” cure (5 seconds vs. 1 second)
  - These factors have now been demonstrated by actual test

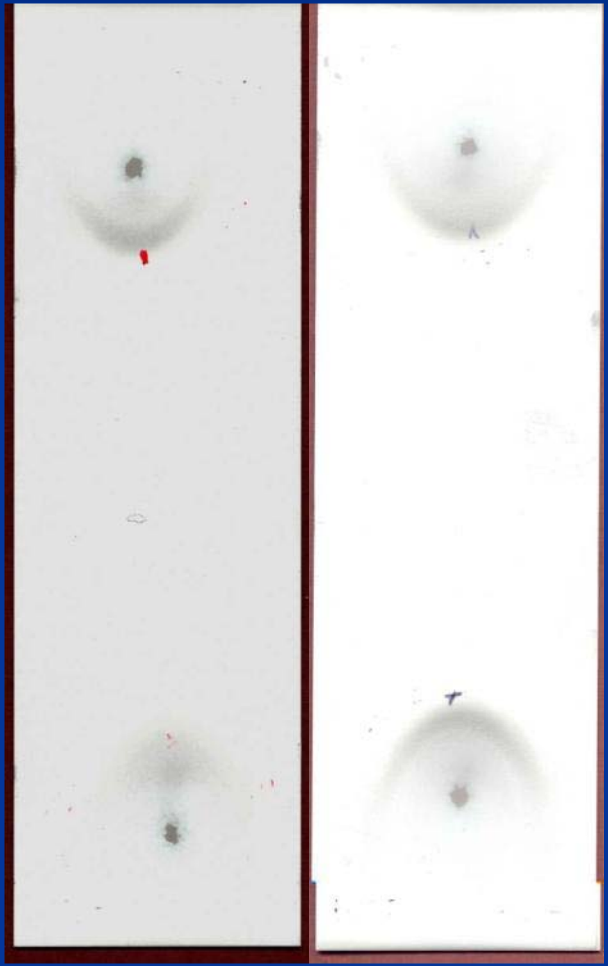
UVCPC Demonstration

- General test results
  - Strippability

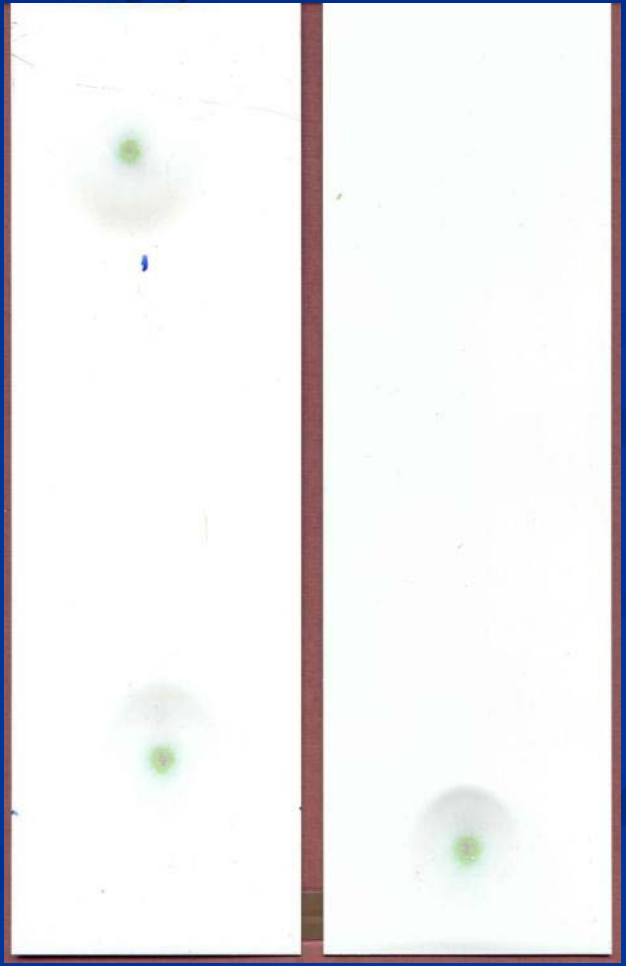
UVCPC Demonstration

- Falling sand testing

UVCPC over 2024 Anodized



Legacy over 2024 Anodized



UVCPC Demonstration

- Actual components coated
  - Coast Guard MC-130 landing gear door
  - Entrained moisture created huge bubble during IR phase

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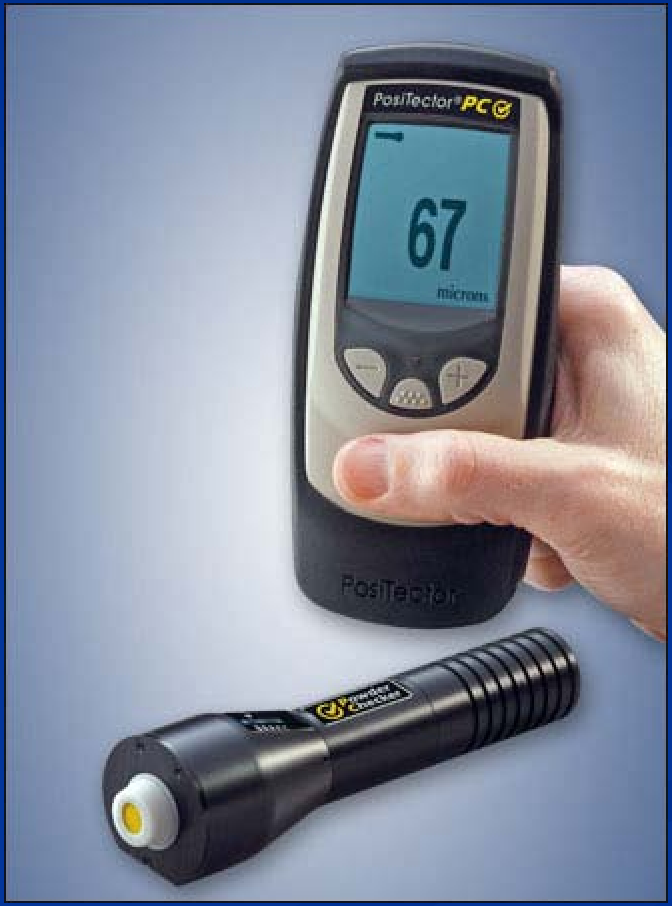
UVCPC Demonstration

- Better Robotic Profiling
  - Use of small radiometers
  - Extended use of thermal profiling

UVCPC Demonstration

- Better Powder Coating
  - Use of non-contact uncured powder thickness gauge



UVCPC Demonstration

- Estimated Cost of Improvements
  - Hardware - $6K
  - Robotics modifications - $12K
  - Coatings reformulation and revalidation - $120K